Progress Towards a Precision Measurement of the Neutron Lifetime Using Magnetically Trapped Ultracold Neutrons

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Abstract. As part of an on-going program utilizing magnetically trapped ultracold neutrons (UCNs), we are developing a technique that offers the possibility of improving the precision of the neutron lifetime by more than an order of magnitude. The experiment works by loading an Ioffe-type superconducting magnetic trap with UCNs through inelastic scattering of 0.89 nm neutrons with phonons in superfluid ^{4}He. Trapped neutrons are detected when they decay; charged decay electrons ionize helium atoms in the superfluid resulting in scintillation light that is recorded in real time using photomultiplier tubes. At present, we are installing a larger and deeper superconducting magnetic trap into our apparatus, implementing techniques to reduce background events, and working to increase the neutron decay detection efficiency. We report the status of the construction of the improved apparatus.

Keywords: neutron lifetime; magnetic trap; superfluid helium; superthermal; ultracold neutron; scintillation

INTRODUCTION

Precision measurements of the neutron beta-decay lifetime τ_n performed during the past two decades using several different techniques have yielded values of τ_n with relative uncertainties of ≤ 0.5 %[1]. Recent values appeared to be consistent with each other within the accuracy of the measurements. The most recent value[2], however, differs from the world average by 6.5 standard deviations from the presently accepted world average[1] and calls into question this consistency. Additional high-precision measurements using different techniques are now even more important.

We are in the process of developing a technique that has completely different systematic effects than previous experiments. This technique employs real-time detection of neutron decay events from ultracold neutrons (UCNs) confined magnetically in an Ioffe-type trap[3,4]. We present a progress report on this experiment.

TECHNIQUE

Ultracold neutrons are produced by the inelastic scattering of cold (0.89 nm) neutrons in a bath of superfluid ^{4}He (the superthermal process[5]). The neutrons are then confined within the ^{4}He by the interaction of their magnetic moment with a three dimensional magnetic trap field. The trapped neutrons travel undisturbed within the trap region until they decay, where the resulting electrons recoil through the helium producing an ionization track. The He_2^* molecules are created in both singlet and triplet states. The singlet molecules decay promptly (<10 ns), producing a prompt emission of extreme ultraviolet (EUV) light. This scintillation light is converted to visible wavelengths (blue) using an organic fluor and detected using photomultiplier tubes. τ_n is determined by extracting the lifetime from the neutron decay rate.

IMPROVEMENTS

Neutron lifetime data acquired using the present apparatus was primarily limited by the number of neutrons confined within the magnetic trap[4]. The measured trap lifetime at 300 mK and with no ameliorative magnetic ramping is substantially shorter than the free neutron lifetime. This is attributed to the previously known systematic effect arising from the presence of neutrons with energies higher than the magnetic potential of the trap. When magnetic field ramping is implemented to eliminate these neutrons, this results in a lifetime of 833+74/-63 s for the trap, consistent with the currently accepted value of the free neutron lifetime.

To increase the number of trapped neutrons, we are in the process of replacing the existing magnetic trap with a larger and deeper trap. This new trap is constructed from a high-current superconducting quadrupole magnet that has two solenoid coils positioned around the outside. This new trap has a trap region with a diameter of 12 cm, length of 75 cm, and trap depth of 3.1 T. We estimate that this magnet will increase the number of trapped neutrons by a factor of twenty.

The quadrupole and the solenoids were independently tested to greater than 90 % of their designed current without quenching. When tested in the Ioffe configuration, the assembly performed at 90 % of the design current after this initial. Additional tests were not performed due to limitations in the liquid helium supply.

The design of a new dewar with sufficient size to accommodate this new magnet is shown in Fig. 1. The dewar consists of a horizontal section that houses the magnetic trap and the vertical sections house the dilution refrigerator and high-current magnet leads. The refrigerator tower is re-used from the existing apparatus. To accommodate the weight of the magnet (~1300 lb) on the horizontal section, two composite support posts have been designed, fabricated, and tested. They support the magnet from the bottom, with minimal heat load (<1.0 W from both posts). The horizontal and second vertical towers are presently being fabricated.

Due to the large heat loads from conventional vapor-cooled current leads, high-temperature superconducting (HTS) leads are being used to transport the current into the liquid helium volume. These leads have been acquired and tested. In addition, to further minimize liquid helium consumption, two 1.5 W at 4.2 K cryocoolers are being incorporated into the design.

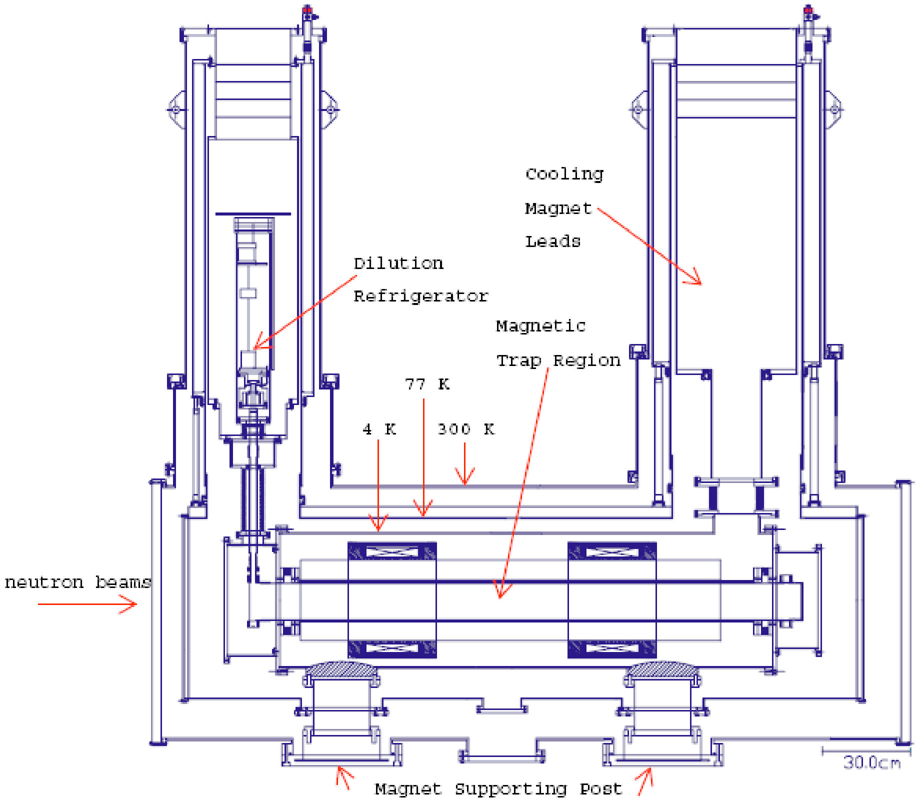

FIGURE 1. Schematic of the quadrupole magnetic trap postioned in the new dewar.

To increase the detection efficiency of the apparatus, we have performed extensive simulations on the light collection and transport systems for both the existing apparatus and our prototype design for the new dewar. Using the light transport code GuideIt, we have modeled the complete detection system, including the development and independent benchmarking of new routines to handle reflections from the diffusive materials surrounding the trap regions. Simulations were performed on the existing system and these data were compared with calibration data using radioactive sources in the apparatus. The two sets of data agree quite well with only one scaling factor (0.3) needed to account for the unknown coverage area of the organic fluor on the diffusive material surrounding the cell.

We estimate that using the improved apparatus, we will be able to perform a measurement of the neutron lifetime with a relative statistical uncertainty of 0.5 % in one reactor cycle (40 d) at the National Institute of Standards and Technology. The experiment could then move to the newly-constructed Spallation Neutron Source at Oak Ridge, where one could make a measurement with a 0.1 % statistical uncertainty due to better coupling of the neutron beam into the apparatus and lower background rates.

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